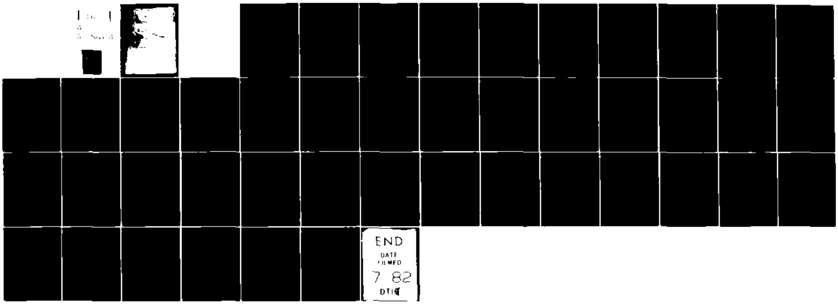
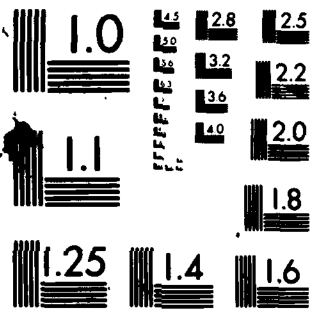
AD-A115 464 ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND DOVER--ETC F/G 10/2
SOLAR ENERGY APPLICATIONS AT ARMY AMMUNITION PLANTS.(U)
JUN 82 A P LOWRY, S M MOY
UNCLASSIFIED ARLCD-TR-81038 SBI-AD-E400 841 NL





MICROCOPY RESOLUTION TEST CHART

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AD A115464

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report ARLCD-TR-81038

2. GOVT ACCESSION NO.
AD-A115 464

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
SOLAR ENERGY APPLICATIONS AT ARMY AMMUNITION PLANTS

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
ARRADCOM, LCWSL
Energetics Systems Process Div (DRDAR-LCM-S)
Dover, NJ 07801

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
ARRADCOM, TSD
STINFO Div (DRDAR-TSS)
Dover, NJ 07801

12. REPORT DATE
June 1982

13. NUMBER OF PAGES
46

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solar energy	Hot process water	Preheat boiler feedwater
Flat plate	X-ray film	Process hot air
Evacuated tube	Laundry	Dryhouses
Solar ponds	Showers	Heating/cooling/hot water
Heat pumps	Melt/pour and washdown	Solar heated building

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Army Ammunition Plants use significant quantities of fossil fuels. To reduce dependence on these scarce, costly, and non-renewable fuels, a study was conducted to investigate potential solar energy applications at the AAPs.

Solar energy is a low-level energy source which is best applied to low temperature applications. It can be used at the AAPs to preheat boiler feedwater, provide hot air for dry-houses, provide domestic hot water and heat for
(cont)

20. ABSTRACT (cont)

administration buildings, and provide hot water for manufacturing processes such as metal cleaning, phosphating, and x-ray film processing.

Use of flat plate collectors, evacuated tube collectors, or solar ponds with the possible addition of a heat pump, offers reasonably economical means of applying solar technology to AAP needs.

CONTENTS

TABLES

FIGURES

INTRODUCTION

Background

In the early 1950's, this nation's demand for petroleum began to outpace its supply. Consequently, it began to import crude oil from foreign sources. This imbalance between internal supply and demand continued to increase until, by 1973, nearly 30% of all domestic use was supplied by foreign imports. During that year the Organization of Petroleum Exporting Countries (OPEC) imposed an embargo on crude oil shipments to the United States, causing severe hardships in both the industrial and private sectors. Even though the embargo was short-lived, it had far reaching consequences, namely, the rapid rise of fuel prices and the creation of a nationwide awareness that fuel supplies are uncertain and subject to instant interruption. Nonetheless, the foreign oil dependency has been allowed to rise to the point where nearly 35% of the United States' requirements are now imported.

The dependent fuel situation is cause for concern that energy in appropriate quantities may not be available to meet future national requirements. Manufacturing costs will certainly be adversely affected by continually rising fuel prices.

The application of solar energy is an alternative way of reducing oil demand. Solar energy is classified as a low-level temperature source which can be used for the production of hot water, low-pressure steam, and comfort heat. Fossil fuels, which can produce combustion temperatures over 1000°F, become inefficient when used to heat water or air to several hundred degrees fahrenheit. This represents a gross mismatch between source and product. Solar energy offers a more efficient method of satisfying low-temperature heating requirements.

Procedure

The study of the potential applications of solar energy systems to the Army Ammunition Plant complex was conducted in three phases.

1. A literature search was performed to determine state-of-the-art technology and economics. The search investigated the Department of Energy and the Army's report files, industrial conference proceedings, and private sector progress reports dealing with applications of solar energy.

2. Several Army Ammunition Plants (AAPs) were surveyed for possible solar applications. Those with the most favorable solar insolation values and climatic conditions were selected for process applications. (Insolation is the rate of delivery of solar energy per unit of horizontal surface and climatic conditions and is measured in langleys.)

3. A relationship was developed between proven solar technology and process applications at the AAPs surveyed: Hawthorne, Kansas, Lone Star, Longhorn,

Louisiana, McAlester, Milan, Mississippi, and Riverbank. Recommendations were made on the basis of payback periods of 15 years or less.

TYPES OF SOLAR SYSTEMS

Most manufacturing processes can be broken down into three temperature levels: high [288°C (550°F) or more)], intermediate [104°C to 288°C (228°F to 550°F)], and low temperature [104°C (220°F) or less].

Only in low temperature manufacturing processes has solar energy proven to have a reasonable payback period. These temperatures can be supplied by solar energy with the use of solar collectors or solar ponds with the possible addition of heat pumps. A partial list of solar installations in industry is included in appendix A.

Intermediate temperature solar systems which are technically feasible include (1) the use of pressurized water which is flashed to steam and (2) the use of an organic heat transfer fluid and heat exchanger. However, the payback period for these systems is over 15 years.

High temperature processes need to be proven both technically and economically feasible. Development is continuing with different types of concentrating collectors. Thermal efficiencies below the goal of 60% to 70% at 316°C (600°F), low durability (a 10- to 20-year life is dictated by economics), and technology that does not lend itself to low labor mass production (ref 1) have surfaced as major problems.

Finally, the direct production of electricity by photovoltaic cells (another solar technology) is beginning, but commercialization of this technology for general use is far in the future.

Low Temperature Solar Systems

Major emphasis should be given to low-level temperature applications when applying solar technology to the Army's energy needs. These applications include the production of hot water, low-level steam, and comfort heat which can be produced by using several proven solar energy systems, including collectors or solar ponds, possibly combined with heat pumps (table 1).

The flat plate and the evacuated tube are two of the commercially available solar collectors suitable for use in low-temperature applications.

Table 1. Low temperature solar systems

System	Description	Cost*	Comments
Flat plate collector	Black absorber plate with fluid passages enclosed with a glazed cover on the top and insulation underneath. Collector is tilted southward.	Single glaze \$97 to \$130/m^2 \$9 to \$12/ft^2 Double glaze \$172 to \$215/m^2 \$16 to \$20/ft^2	Low temperature level application up to 82°C (180°F) High efficiency (60% to 80%) Requires little maintenance Uses both direct and diffuse sunlight
Evacuated tube	Tubular configuration with an evacuated insulation chamber.	\$215 to \$270/m^2 \$20 to \$25/ft^2	Higher temperature output 100°C (212°F) High efficiency (up to 90%) Collects direct and diffuse sunlight
Salt-gradient pond	Pond filled with salt water, which creates multiple layers of salt concentration. The top layer acts as an insulator; the lower layer absorbs solar energy and acts as a thermal storage unit. Pond depth ranges from 1 to 3 m (3 to 10 ft).	Not available	High efficiency Combined absorbing and storage unit Requires cheap salt and large area In experimental stage in U.S.
Shallow solar pond	Plastic water bag within an insulated enclosure. Water depth ranges from 75 to 150 mm (3 to 4 in.)	\$ 75 to \$161/m^2 \$7 to \$15/ft^2	Limited to low temperature application Maximum temperature 43°C (110°F) Collection efficiency range 30% to 50% Low cost
Heat pump	Thermodynamic power cycle capable of raising fluid temperature by extracting heat from a heat source.	Size varies according to manufacturer	Can be incorporated with any of the above systems Cycle uses electricity to extract heat

* 1981 dollars

Flat Plate Collectors

A flat plate collector (fig. 1) consists of transparent cover plates, an absorber plate, fluid passages, insulation, and framing and are mounted on the ground or on a rooftop facing south and tilted at an angle usually within 10° of latitude. Incident solar radiation, both direct and diffuse, enters the collector through the transparent cover sheet and strikes the absorption plate. At the absorber plate, radiant heat energy is transformed into thermal energy which is transported in the fluid passages of the collector to a storage tank or heat exchanger.

Flat plate collectors are potentially useful in supplying low-grade thermal energy at temperatures less than 82°C (180°F) and may be used in systems which supply domestic or industrial hot water and in space heating and cooling applications. Costs, excluding labor, are given in table 1 (ref 2).

Evacuated Tube Collectors

Evacuated tube collectors (fig. 2) use an evacuated insulation chamber to reduce heat losses due to convection and conduction. Radiant heat energy is transformed into thermal energy at the outer surface of the inner tube; the thermal energy is transported by the system fluid that will be used for the appropriate application. Evacuated tubes are generally able to achieve higher efficiencies than flat plate collectors and are useful for slightly higher temperature applications.

The evacuated tube tends to maintain a stable efficiency through the day because of its configuration and capability of collecting a higher percentage of the diffuse component of incoming solar radiation. Current costs range from \$215 to \$270/m^2 (\$20 to \$25/ft^2) (ref 2).

The temperature required for the process, the expected performance of the collector in a specific location, and the expected temperature of the tansfer fluid at the inlet to the collector are factors which must be considered in selecting a collector.

Solar Ponds

Solar ponds have the potential for producing cost effective, low-temperature thermal energy. The two types of ponds for collecting solar energy are the nonconvecting, salt gradient pond and shallow solar pond.

The three-layered salt gradient pond (fig. 3) has a surface convecting layer, a nonconvecting layer, and a bottom convecting storage layer. The surface convecting layer contains unsalted water as the transporting fluid and is the area where the solar radiant heat is transformed into thermal energy. The bottom two layers contain different levels of salt concentration and are dyed to a

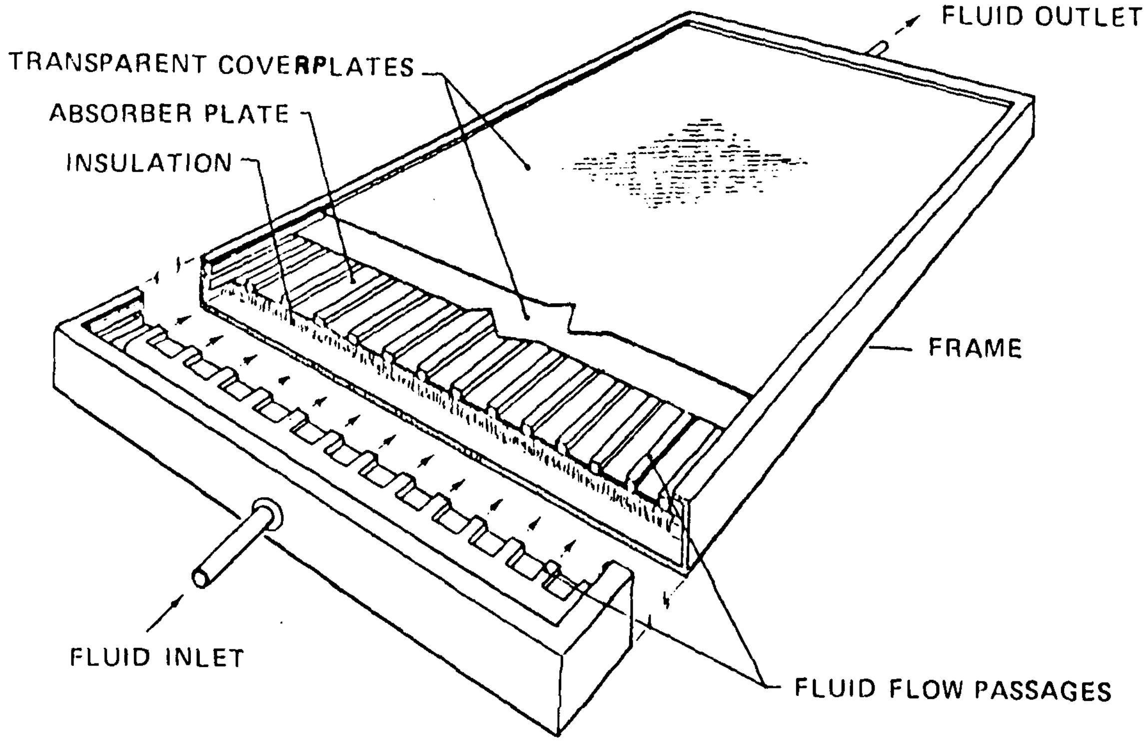

Figure 1. Basic flat plate collector

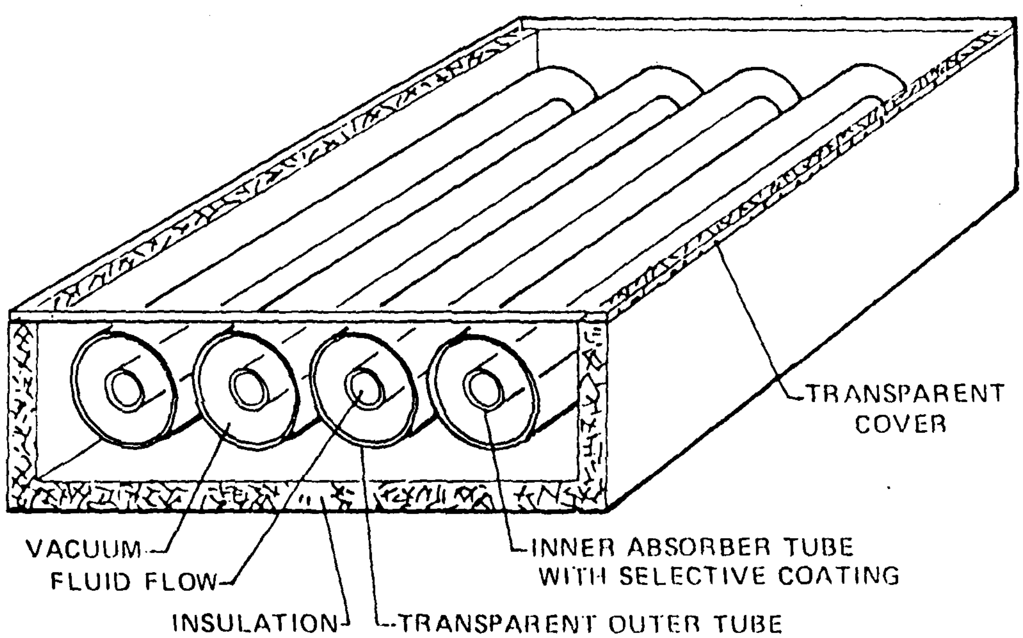

Figure 2. Evacuated tube solar collector

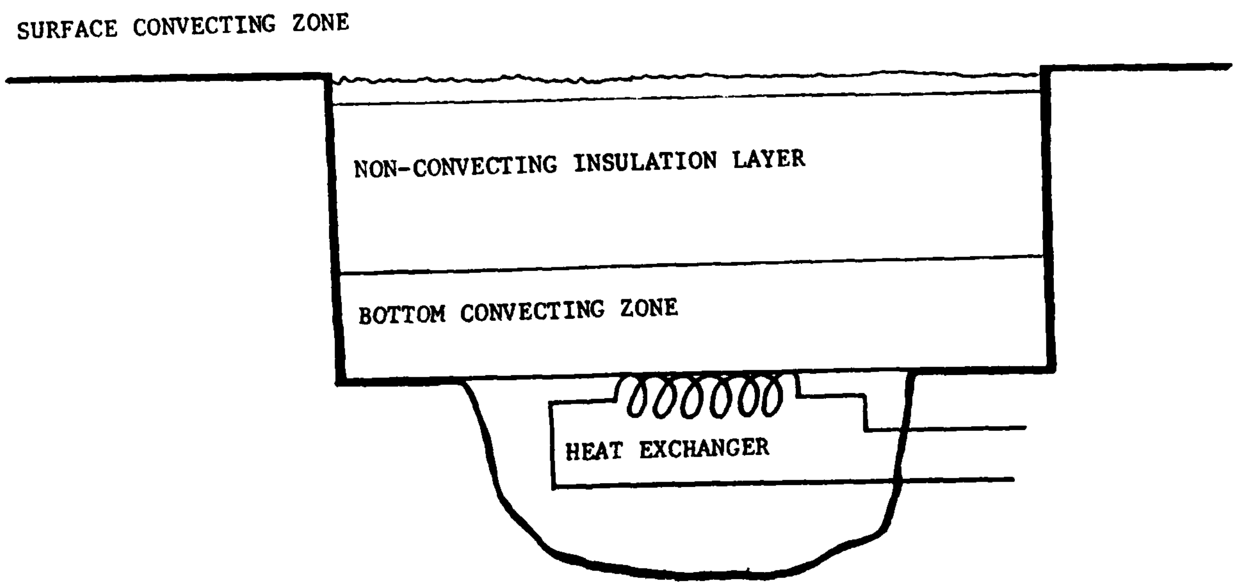

Figure 3. Cross-section of a salt gradient pond

darker color to absorb the thermal energy. Without varying the salt concentration, a normal thermal convection pattern would develop, in which the warmer (dark colored) bottom liquid layer would rise due to buoyant effects and would lose its thermal energy at the surface. But, with a salt-gradient pond, this thermal pattern is suppressed by dissolving more salt at the bottom than at the top. The salt gradient offsets the thermal density and prevents thermal convection. The nonconvecting salt layer acts as an insulator for the convecting layer and also provides thermal storage. Under optimum operating conditions, the storage layer can almost reach the boiling point of water, while the surface layer is at ambient air temperature. Thermal energy is extracted from the bottom convecting layer by various exchange techniques. The typical solar pond depth ranges from 1 m to 3 m (3 ft to 10 ft) (ref 3). There are few nonconvecting, salt gradient ponds in the United States, but they have reached commercialization in Israel because of the availability of natural bodies of saline water.

Shallow solar ponds (fig. 4) consist of a plastic water bag contained within an insulated enclosure, covered with a transparent glazing. The pond is filled in the morning, usually with pure water which will absorb the incoming solar radiation. When the fluid reaches the required temperature, it is either incorporated directly into the process or drained into an insulated storage tank. Shallow solar ponds, without the use of a heat pump, can reach a temperature of 43.3°C (110°F). They are useful in areas where local climatic or soil conditions make it impossible to use salt-gradient ponds. They can be retrofitted on large flat roofs if the supporting structure is adequate. Finally, shallow solar ponds are attractive for low-temperature applications because of the low initial costs (table 1, ref 3).

Solar ponds offer cost advantages over flat plate and evacuated tube collectors. A listing of estimated costs for shallow-solar pond modules developed from the Lawrence Livermore Laboratory can be found in appendix B. Total costs per unit area, material, and installation range from \$75 to \$161/m^2, while total costs for flat plate collectors range from \$107 to \$215/m^2, and evacuated tubes range from \$215 to \$279/m^2. Analyses must be performed to determine optimum economic pond size. Nonconvecting, salt-gradient, solar ponds have reduced costs due to the combination of solar collection, energy storage, and transport within the body of the pond.

Solar ponds have certain constraints on their use including:

1. Availability of large land area
2. Availability of water or brine
3. Free or cheap salt
4. Appropriate soil conditions
5. Maintaining salt-gradient in pond

Heat Pumps

The addition of a heat pump to a solar system will result in achieving temperatures up to 104°C (220°F) with less unit area. The heat pump amplifies temperatures by means of an external heat source and the input of electrical

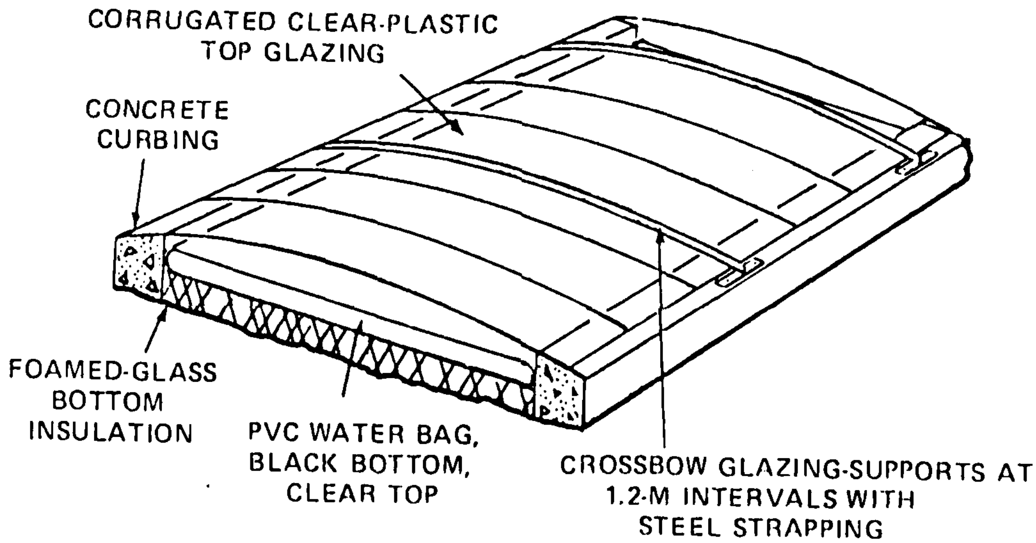

Figure 4. Shallow solar pond

power. The advantage of using a heat pump is that solar heat can be collected at low temperatures and high efficiency which results in a decrease in collection area and a savings in capital costs (fig. 5).

Westinghouse Corp. has developed a solar-system heat pump which functions as follows:

Step 1. Evaporator--Heat from the solar source fluid is absorbed into the heat pump's evaporator by the unit's refrigerant.

Step 2. Motor Compressor--The compressor increases the pressure of the refrigerant and raises the temperature. At this point the temperature amplification takes place.

Step 3. Condenser--The high temperature refrigerant transfers heat to the circulating delivery fluid. The heat transfer includes both the solar heat and the heat equivalent of the electric energy used to drive the compressor. Useful heat up to 104°C (220°F) is provided.

Step 4. Expansion Valve--The refrigerant cycle is completed when the condensed refrigerant passes from the condenser through the expansion valve to the evaporator.

The advantages of a solar-heat pump system over a solar-only system include:

1. Higher overall solar system efficiency

2. Use of lower cost solar collectors, if temperature requirements are below 65°C (150°F)

3. Recovery and re-use of low-temperature waste heat concurrently with solar heat as a source to the heat pump

4. Reduced space requirements for use where the collector area is limited

Intermediate Temperature Solar Systems

The intermediate process temperature range is defined as 104°C to 233°C (220°F to 550°F). Intermediate temperatures can be reached by use of line focusing parabolic trough collectors combined with an organic heat transfer fluid/heat exchanger or pressurized water/flash separation. The latter configuration involves pressurized water circulated through the collector field, then flashed to steam in a low pressure chamber. The organic heat transfer fluid/heat exchanger circulates an organic fluid through the collector array and is then fed to a steam generator where the fluid serves as a heat source to produce steam through a heat exchanger.

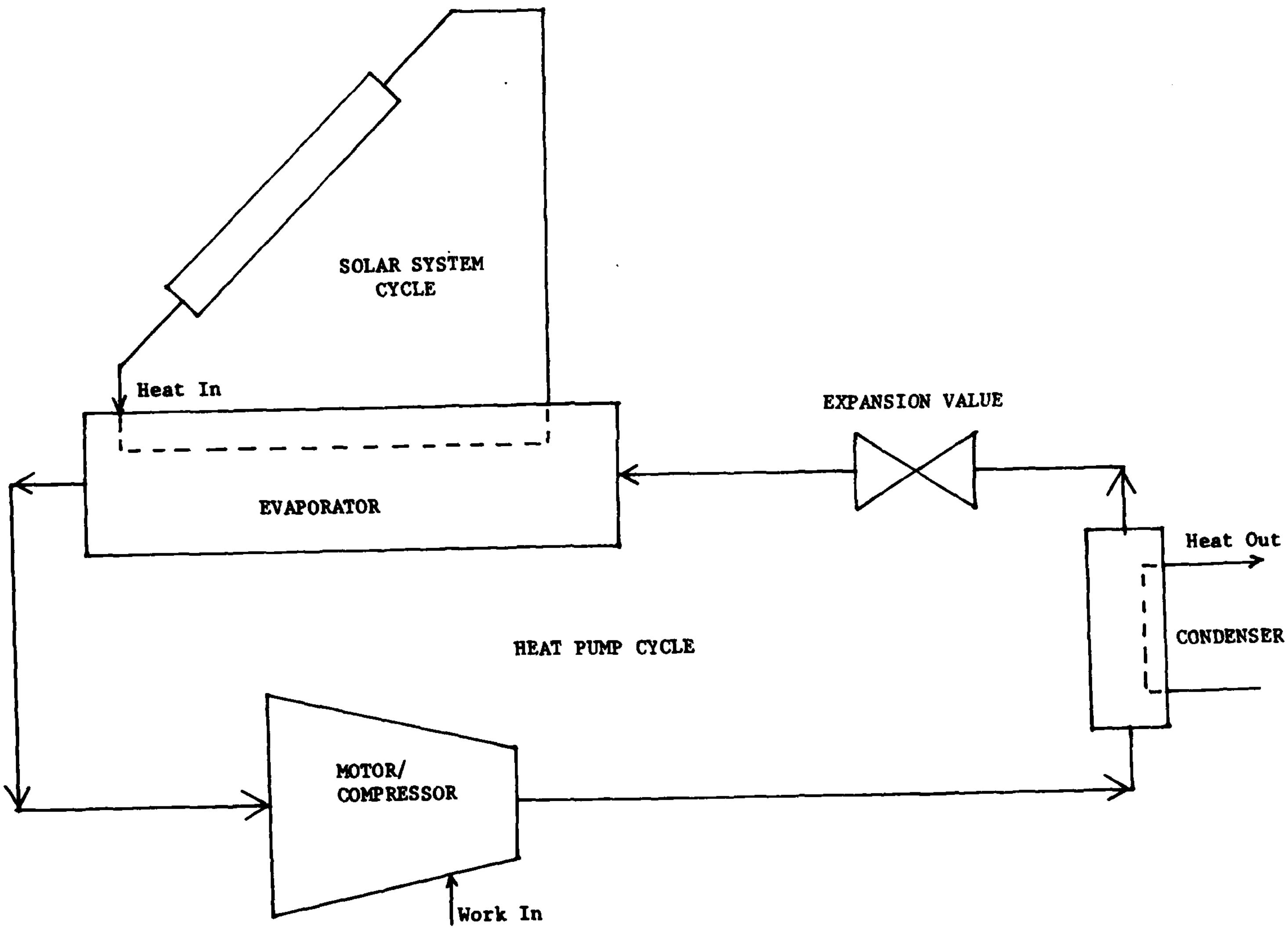

Figure 5. Solar and heat pump system

Several projects are in progress, funded by the Department of Energy and private contractors, to provide a portion of the steam requirements of a variety of industrial processes including oil heating, latex production, oil refining, brewing, and potato processing. The current intermediate temperature projects are basically demonstration projects partially funded by the Department of Energy (DOE). Without DOE funding, the payback would be over 20 years. Technology research and development are required to develop systems without technical problems and with a reasonable economic payback.

High Temperature Solar Systems

High temperature solar systems remain in the experimental stage, with development continuing to eliminate technical problems. These systems are not suitable for AAP application at present.

Photovoltaic Cells

Photovoltaic technology uses incident sunlight to directly produce electricity. The theory behind this effect is that an electric current is created when a light photon strikes certain semiconductor materials.

Photovoltaic cells can be arranged in either flat plate or concentrating arrays. Flat plate arrays cost less but are also less efficient. Concentrating arrays use fresnel lenses, mirrors, and compound parabolic concentrators to increase the amount of light energy that strikes the photovoltaic array. Concentrators increase the conversion efficiency of a photovoltaic cell, which offsets the higher cost per cell.

The cost per kilowatt-hour is above that produced by the utility industry. Photovoltaic research is aimed at reducing the cost of making solar cells, so that electricity produced from the cells will be cost competitive with, and eventually cheaper than, electricity produced from burning fossil fuels. Until the economics of solar cells decrease to a cost level comparable to currently produced electricity, solar cells should not be considered when payback is a major requirement.

POTENTIAL SOLAR ENERGY PROJECTS AT ARMY AMMUNITION PLANTS

Based on this study, solar applications were proposed for the six plants listed in table 2.

Table 2. Potential solar AAP projects

AAP	Solar system	Application	Capital cost ($K)	Estimated oil savings (gal./yr)	Payback (yrs)
Kansas	Evacuated tube and concentrating collector	Melt/pour and washdown	460	12,900	18
	Flat plate collector	700 detonator line hot air for dry house	Further analysis required		
	Flat plate collector	155-mm projectile line	Further analysis required		
		1. Hot water for shower			
		2. Freon-nest cleaning units			
Lone Star	Shallow solar pond or solar pond plus heat pump	Preheat boiler feedwater for G-29 boiler house	94	4,500	8.4
			135	4,600	14.4
Longhorn	Shallow solar pond	Preheat boiler feedwater for central boiler plant	Further analysis required		
	Shallow solar pond	Preheat feedwater for satellite boilers of:	Further analysis required		
		1. Administrative area			
		2. 814 area			
	Shallow solar pond	Hot water for humidity controlled building	Further analysis required		

Table 2. (cont)

AAP	Solar system	Application	Capital cost ($K)	Estimated oil savings (gal./yr)	Payback (yrs)
Louisiana	Undetermined	Partial solar heating and cooling of administration building	Further analysis required		
Milan	Shallow solar pond	Hot water for X-ray film processing equipment	75	2,720	7
		Preheat boiler feedwater for line X	192	6,400	10
		Hot water for laundry	90	2,500	13
Riverbank	Shallow solar pond or solar pond plus heat pump	Hot water for metal cleaning and phosphating solutions	185	9,000	9
			230	11,600	9

Kansas AAP

Melt/pour and Washdown

Solar energy for the exlosive melt/pour and washdown processes at Kansas AAP was proposed by AAI Corporation.

The melt/pour process requires a constant high temperature for 8 hours a day, 5 days a week. For example, if 4.54 X 10^5 kg (1 X 10^6 lb) of Comp B explosive per month is heated from a solid at 21°C (70°F) to a liquid at 93°C (200°F), the process heat required for this operation is 1.96 X 10^6 kJ/day (1.86 X10^6 Btu/day) or 13.7 X 10^6 kJ/wk (13 X 10^6 Btu/wk).

The washdown process requires a large supply of relatively low-temperature heat for a weekly 2-hour period. Both the melt/pour and washdown processes are performed in the same facility, and the washdown process occurs after the weekly completion of the melt/pour process. A 570 L/min (150 gpm) at 71°C to 82°C (160°F to 180°F) is needed for this operation. Thermal energy required is 19.7 X 10^6 kJ/wk (18.7 X 10^6 Btu/wk).

The solar system proposed by AAI Corporation consists of a 595 m^2 (6,400 ft^2) solar collector array, two steel thermal storage tanks (a 6,500-gal. pressure tank and 11,500-gal. non-pressure tank), a solar collector pump, and various associated valves, piping controls, and instrumentation.

The collectors, 24/1 concentrators, would be manufactured by AAI Corporation. The solar system would operate by using the sun's radiant energy to heat water and glycol (antifreeze) solution in the collectors. The heated liquid, 150°C (300°F) maximum circulated by the collector pump, then would be routed to either a tank-type heat exchanger located in the 6,500-gal. tank, the melt/pour heating receptacle, or both. The 6,500-gal. tank is for thermal storage in the melt/pour system and would provide the necessary stored heat for morning or cloudy day operation. However, since the operational period for the melt/pour process roughly coincides with the operational period of the solar collectors, the hot water directly from the collectors would provide most of the process' required heat. Excess solar heat collected on days of high insolation, weekends, or holidays, would be stored in the 11,500-gal. thermal storage tank. The heat from this tank plus the heat from the 6,500-gal. tank would provide the heat for the washdown process which occurs after the melt/pour process has been completed for the week. In the event that solar energy is unavailable, or if additional supplementary heat is required, boilers would provide the necessary auxiliary heat.

The proposed solar system would be sized to supply approximately 77% of the yearly heat requirements (high temperature water) for the melt/pour process and approximately 70% for the washdown process.

The economic statistics for the two processes are as follows:

Melt/pour process

Total energy required	= 13.7 X 10^6 kJ/wk (13 X 10^6 Btu/wk)
Energy supplied by system	= 5.49 X 10^8 kJ/yr (5.2 X 10^8 Btu/yr)
Oil equivalency	= 3,720 gal./yr
Include boiler efficiency (0.7)	= 5,310 gal. oil saved/yr

Washdown process

Total energy required	= 19.7 X 10^6 kJ/wk (18.7 X 10^6 Btu/wk)
Solar energy supplied	= 7.9 X 10^8 kJ/yr (7.5 X 10^8 Btu/yr)
Oil equivalency	= 5,350 gal./yr
Include boiler efficiency (0.7)	= 7,643 gal. oil saved/yr

Total oil saved: 7,640 + 5,310 = 12,950 gal./yr
Solar system cost: $460,000
Payback: 18 years

155-mm Projectile Line

Electric resistance heating is used to heat water up to 60°C (140°F) for the shower area and freon-nest cleaning units. Kansas AAP purchases its electricity from a nearby utility. As electric costs increase yearly, so does the cost of heating the water.

Kansas AAP has suggested that a flat plate collector system be used to produce the hot water for shower and freon-nest cleaning units. Flat plate collector units have proven to be feasible for producing hot water in the residential and industrial sectors. The major benefit of using the solar system would be the reduction in the electrical load. The flat plate collector system would use the present storage system, so that resistance heating may be used as the back-up. This will result in a savings in the capital costs, of which the collectors are the major cost factor. At present, there is insufficient design data available to evaluate this proposal.

Detonator Line--700 Area

Another possible solar energy application is the detonator line's paint dry houses located in the 700 area. The dry houses are enclosed rooms in which hot air, 60°C to 65°C (140°F to 150°F), is circulated to heat-dry paint on the detonator process line. The present method of producing hot air utilizes a fossile-fueled boiler system. The boiler is used sporadically which results in a very low efficiency.

Since the air temperature requirements are in the low-level range and the boiler system is run in an inefficient manner, solar energy could replace the current method. A solar system composed of evacuated tubes or flat plate collectors, using air as the heat transporting fluid, is a possibility. This could eliminate the need for a heat exchanger system and lower capital costs. At present, there is insufficient design data available to evaluate this proposal.

Lone Star AAP

About 75% of Lone Star AAP's energy consumption consists of boiler and heating fuel. Most of this fuel is used at five production area boiler houses to generate steam. Since Lone Star is located in the sunbelt area, solar energy can be collected with relatively high efficiency. A flat plate solar panel system was installed at boiler house Q-36 to preheat boiler make-up feedwater.[1] There are 115 panels each with a gross area of 2 m^2 (20.71 ft^2) for a total of 221 m^2 (2381.7 ft^2). The panels are piped in arrays of five 11-panel rows and five 12-panel rows. Water is circulated through the array at a rate of 190 L/min (50 gal./min). The heat is transferred to make-up water through a shell and tube type heat exchanger and stored in a surge tank. Initial testing shows that the average amount of energy delivered by the system is about 343,000 kJ/hr (325,000 Btu/hr) and the average outlet temperature is about 65°C (150°F). Additional testing is underway.

A solar pond and heat pump system has been proposed to preheat make-up boiler feedwater at boiler house G-29. This proposed system would be capable of delivering 3780 L/hr (1000 gal./hr) of preheated water.

The system would consist of two 5 X 30 m (16 X 100 ft) shallow solar pond modules, two 7,000-gal. insulated water tanks, one high-temperature heat pump, and operating and connecting hardware. In the late afternoon, when the pond water attains its highest temperature, the warm water would be pumped into the hot insulated storage tank. Boiler make-up feedwater would be preheated by pumping warm water from the hot storage tank to a heat pump. The function of the heat pump would be to extract thermal energy from the warm water stream to the make-up feedwater stream.

[1]DRC Project 5792006.

During the warm season, the outlet water temperature from the pond is about 43°C (110°F). The addition of a heat pump to the pond would produce about 71°C (160°F) make-up feedwater.

The estimated project cost for a solar pond and heat pump is $135,000 with a savings of 4,600 gal./yr and an estimated payback of 14.4 years.

Longhorn AAP

Central Boiler Plant

Two boilers have been fitted with heat recovery equipment to preheat a fraction of the boiler feedwater. A shallow solar pond could be used to preheat additional feedwater. The amount of energy to be supplied by the pond will depend on an economic evaluation.

Satellite Boilers

Preheating boiler feedwater by shallow solar ponds can be used at two active satellite boiler houses located at the 814 production area and at the administration building. The 814 area of the central boiler plant can be a suitable location for installing a shallow solar pond and can be used for comparison with the present Lone Star flat plate collector system. A preliminary design analysis was performed and the results are contained in appendix B.

The administration building's requirement for hot water and comfort heat can be partially supplied by solar energy. A flat plate collector system is a possible choice to supply the load, and the amount supplied will depend on further evaluation by the AAP.

Humidity Controlled Buildings

Certain buildings require low-temperature steam for comfort heat and humidity control. The present method uses an oil-fired boiler to produce low temperature steam 104°C (220°F). A flat plate collector or evacuated tube system could possibly supply solar heated water about 93°C (200°F) in lieu of steam.

Louisiana AAP

Louisiana AAP suggested that solar energy be used to partially supply the heating, cooling, and hot water load of the administration building. Since comfort heating and domestic hot water are low temperature requirements, solar energy would be an efficient means of providing the load. Solar collectors,

evacuated tubes, or flat plates could be mounted on the roof or on a nearby stretch of land. Louisiana is performing an analysis to determine the initial design criteria for incorporating a solar system.

Milan AAP

X-ray Facility

A new x-ray film processing facility was recently constructed at Milan AAP which uses steam to heat the process water. Three process lines are operating, with each line requiring 13 L/min (3.5 gal./min) of heated water at 22°C (72°F). The steam is produced from an isolated boiler house, the main function of which is to provide comfort heat during the winter; however, the boiler must remain in operation year round to supply steam to heat the x-ray facility's process water. This method is inefficient. Oil is used in nonheating periods to provide steam [104°C (220°F)] which is used to produce heated water at 22°C (72°F).

The Tennessee Valley Authority (TVA) suggested that process water be produced by using a shallow solar pond, eliminating the need for operating the boiler house between May and September.

TVA estimates that a shallow solar pond area of 149 m^2 (1600 ft^2) would supply the local requirements. This could be broken down into two-pond modules 2.5 m (8 ft) wide, 30.5 m (100 ft) long, and 100 mm (4 in.) deep. Estimated capital costs are $75,000 with projected annual savings of 2,720 gal. of oil and a payback of 7 years.

Line X Boiler House

Line X uses an oil fired satellite boiler house to produce process steam. To reduce the oil demand at Milan, it was suggested that a shallow solar pond be incorporated into the present boiler system to provide heated feedwater at temperatures between 29°C and 38°C (85°F and 100°F). Milan estimated that a pond area of 595 m^2 (6400 ft^2) would be needed. Capital cost was estimated to be $192,000 with an estimated payback of 10 years and a return on investment of 16.3%. A flat plate collector system was compared to the proposed pond, and payback was calculated to be greater than 15 years.

Laundry Process Water

The laundry process requires significant quantities of hot water. To reduce the oil demand, solar could be used to assist the current, oil-fired method. Milan estimated that a pond area of 121 m^2 (1300 ft^2) would meet the

load requirements at an estimated capital cost of \$64,000. The estimated payback is 13 years, with a return on investment of 11.5%.

Riverbank AAP

The heating of metal cleaning and phosphating solutions at Riverbank AAP uses 30,000 lb of steam per hour per line. The current method of heating the process water is by steam generated by oil- or gas-fired boilers or electrical resistance heaters.

Solar ponds in conjunction with heat pumps can be used to deliver the hot process water. Located in the sunbelt area, Riverbank has a climate which would support solar heating. There are clear days over two-thirds of the year with the average temperature at 23°C (74°F) but frequently exceeding 38°C (100°F) in the summer. The average annual high solar insolation is about 19,000 kJ/m^2 per day (1670 Btu/ft^2 per day).

Solar ponds can be placed on the roof of the two-story metal cleaning building which is strong enough to support them. During late afternoon, when the pond water reaches its highest temperature, the warm water would be pumped to and stored in an insulated storage tank. Hot process water, which can be as high as 85°C (185°F), would be delivered by extracting heat energy from the solar pond water with a heat pump.

For a solar pond area of 650 m^2 (7000 ft^2), approximately 1310 X 10^6 kJ/yr (1240 MBtu/yr) of solar energy could be collected. The combination of heat pump and solar pond is estimated by supplying 1688 X 10^6 kJ/yr (1600 MBtu/yr) of the energy requirements. This results in annual savings of 11,600 gal. of oil with an estimated capital cost of \$230,000 and a payback of 9 years.

Solar Ponds for Preheating Boiler Feedwater

The application of shallow solar pond technology to preheat boiler feedwater was proposed by Lone Star, Longhorn, and Milan AAPs. A brief economic analysis of shallow solar ponds is contained in appendix B. The quantity of energy to be supplied by solar pond technology was assumed to be 654 X 10^6 kJ/yr (620 MBtu/yr), which is equivalent to the output of the flat plate collector system at Lone Star AAP. The pond sizing procedure used was developed by Lawrence Livermore Laboratories and the results are given in table 3. Insolation and temperature data was obtained from weather stations in Milan, Tennessee; Shreveport, Louisiana; and Texarkana, Texas.

Table 3. Payback period estimates

AAP	Pond area (m^2)	Pond area (ft^2)	Estimated costs ($)	Payback (yrs)	Savings (gal. oil/yr)
Milan	446	4800	112,500	10.0	4500
Longhorn	372	4000	94,000	8.4	4500
Lone Star	372	4000	94,000	8.4	4500

CONCLUSIONS

1. Solar energy is a viable energy source for low-temperature [104°C (220°F)] applications. The most cost effective use is for heating water in the range of 37°C to 82°C (100°F to 180°F).

2. Flat plate and evacuated tube collectors are more efficient and produce higher temperatures [82°C (180°F)], but have a higher capital cost than solar ponds.

3. Solar ponds have the lowest installed cost per area but generate lower temperatures [37°C (100°F)].

4. A heat pump can increase solar energy system efficiency by increasing output temperature [104°C (220°F)] and reduce collection areas and capital costs.

5. The preliminary survey of selected AAP's, located in favorable insolation areas, identified several potential energy applications including preheating of boiler feedwater at Lone Star, Longhorn, and Milan; domestic hot water and comfort heating of the administration buildings at Louisiana and Longhorn; hot water for x-ray film processing and for clothes laundering at Milan and hot water for metal cleaning and phosphate solutions at Riverbank.

6. The use of concentrating collectors to supply hot water for the melt/pour loading appears promising but requires additional data. Consideration should be given to an MMT project to fully establish the technique involving this intermediate temperature application.

7. Solar energy systems that produce intermediate and high temperatures and the photovoltaic cell are not economically feasible at this time.

RECOMMENDATIONS

1. Projects should be solicited for the following solar energy applications:

Lone Star AAP - Boiler feedwater

Longhorn AAP - Boiler feedwater

Milan AAP - Boiler feedwater, x-ray film processing, and clothes laundry

Riverbank - Metal cleaning and phosphate solutions

2. Additional information is needed to evaluate potential projects at Longhorn, Louisiana, and Kansas AAPs.

3. Other AAPs located in favorable insolation areas (McAlester, Hawthorne, Mississippi) should be studied to identify potential solar energy applications.

4. An MMT project proposal should be initiated to investigate the use of concentrating collectors to provide hot water for the melt/pour operations at Kansas AAP.

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2. "The Solar-Augmented Applications in Industry," Final Report, Gas Research Institute, 1979.

3. S. L. Sargent, "An Overview of Solar Ponds," Proceedings of the Solar Industrial Process Heat Conference, sponsored by the Solar Energy Research Institute, October 31 to November 2, 1979.

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APPENDIX A
SOLAR INSTALLATIONS IN INDUSTRY

SOLAR INDUSTRIAL PROCESS INSTALLATIONS IN UNITED STATES - YEAREND 1979

LOCATION	USAGE	TEMPERATURE	COLLECTOR TYPE/SIZE	TRANSFER FLUID	STORAGE
GOLD KIST SOYBRAN Decatur, Alabama	Soybean Drying	140- 180° F	Flat Plate/ 13,104 $ft.^2$	Air	None
CAMPBELL SOUP Sacramento, California	Can Washing	195° F	Flat Plate/ 4,500 $ft.^2$ Parabolic Trough/ 2,880 ft^2	Water	20,000 Gallon Insulated Steel
ANHEUSER BUSCH Jacksonville, Florida	Beer Pasteurization	160° F (250°F Potential)	Evacuated Tube/ 4,603 $ft.^2$	Proprietary Heat Transfer Fluid	Thermelt Capacitor Envelopes
LAMANUZZI and PANTALEO Fresno, California	Raisin Drying	150° F (250°F Potential)	Flat Plate/ 21,600 $ft.^2$	Air	14,000 $ft.^3$ of River Rock in a Silo
GILROY FOODS Gilroy, California	Onion Dehydration	160- 212° F	Evacuated Tube/ 6,048 ft^2	Water	None
TROPICANA PRODUCTS Bradenton, Florida	Orange Juice Pasteurization	To 400° F	Evacuated Tube/ 10,000 ft^2	Water	None
BARKLEY MEAT COMPANY South Lake Tahoe, Ca.	Sanitation	180° F	Flat Plate/ 2,500 $ft.^2$ (Approximately)	Water	800 Gallon "Hollow Form" Tank with 4" Insulation
ORE-IDA FOODS Ontario, Oregon	Potatoe Cooking and Processing	417° F	Parabolic Trough/ 10,000 ft^2	Water	None
LONE STAR BREWING San Antonio, Texas	Process Steam	351° F	Parabolic Trough	Water	None
RIEGEL TEXTILE LaFrance, So. Carolina	Fabric Dying	190- 270° F	Evacuated Tube/ 6,680 ft^2	Glycol	8,000 Gallon
WESTPOINT PEPPERELL Fairfax, Alabama	Textile Drying	380° F	Parabolic Trough/ 7,500 ft^2	Water	

LOCATION	USAGE	TEMPERATURE	COLLECTOR TYPE/SIZE	TRANSFER FLUID	STORAGE
BLOTLE AMERICA Shenandoah, Georgia	Process Steam		Evacuated Tube		
J. A. LACOUR KILN SVC. Canton, Mississippi	Kiln Drying Hardwoods	160° F	Flat Plate/ 2,500 ft^2	Water	5,000 Gallon Steel
DOW CHEMICAL Dalton, Georgia	Latex Production		Segmented Mirror		
STAUFFER CHEMICAL Henderson, Nevada	Chlorine Manufacture		Parabolic Trough		
YORK BUILDING PRODUCTS Harrisburg, Pennsylvania	Concrete Block Curing	180- 200° F	Segmented Mirror/ 9,216 ft^2	Water	None
DANA CORPORATION Auburn, Indiana	Machine parts Cleaning and Coating	130° F	Flat Plate/ 900 ft^2	Glycol	3,000 Gallon with Polyurethane Foam
GENERAL EXTRUSIONS Youngstown, Ohio	Aluminum Anodizing (Cleaning Process)	170 - 180° F	Parabolic Trough/ 4,400 ft^2		None
DOS HOME LAUNDRY Pasadena, California	Cleaning Steam and Hot Water	420° F	Parabolic Trough/ 6,496 ft^2	Water	Tank
EASCO PHOTOLAB Richmond, Virginia	Photographic Processing			Water	
RED STAR INDUSTRIAL SERVICE LAUNDRY Fresno, California	Hot Water for Laundry	120 - 160° F	Flat Plate/ 6,720 ft^2	Water	12,000 Gallons
M & M MARS CANDY Waco, Texas	Cafeteria Now, Expanding to Process Use			Water	

APPENDIX B
SHALLOW SOLAR PONDS FOR PREHEATING BOILER FEEDWATER

MILAN ARMY AMMUNITION PLANT

Shallow Solar Pond Peformance Prediction

Shallow solar pond dimension parameters based on annual operation

Area: To be determined

Pond depth: 3 inches

$T_{Ambient}$: 60.5°F

$T_{inlet\ to\ pond}$: 50°F

ΔT (from graph) = 35°F

$T_{out\ from\ pond}$ = 85°F

Design load equals 620 MBtu/yr

$Q = mc\Delta t$

"Parameters"

Q: energy absorbed (Btu)

m: mass flow rate (lb/day)

$m = p \times v$

p: density of water (62.4 lb/ft^3)

v_f: volumetric flow rate (ft^3/day)

c: specific heat of water (1.0 Btu/lb °F)

T: temperature change in pond water (°F)

Q = energy load on daily basis

$$= \frac{620 \text{ MBtu/yr}}{240 \text{ days/yr}} = 2.58 \text{ MBtu/day}$$

$$2.58 \text{ MBtu} = 62.4 \text{ lb/ft}^3 \times v_f \text{ ft}^3\text{/day} \quad (1.0 \text{ Btu/lb °F})$$

$$v_f = 1180 \text{ ft}^3 = \text{area} \times \text{depth}$$

$$\text{Area} = \frac{1180 \text{ ft}^3}{0.25 \text{ ft}} = 4720 \text{ ft}^2$$

Storage = 1180 ft^3 X 7.48 gal./ft^3 = 8826 gal. (assume 9000 gal.)

Milan Payback Period Estimate

Estimated cost for three SSPs (16 ft X 100 ft each)

Total area = 4800 ft^2

Material and installation	$92,500
Design and engineering	20,000
	$112,500

$$\text{Estimated annual fuel savings} = \frac{620 \text{ MBtu}}{5.8 \frac{\text{MBtu}}{\text{bbl oil}}} = 107 \text{ bbl oil} = 4500 \text{ gal. oil}$$

Estimate increase of oil so that average price per gallon at mid life of pond (10 yr life) = $2.50/gal.

$$4500 \text{ gal./yr} \times \$2.50/\text{gal.} = \$11,250$$

$$\text{Payback period} = \frac{\$112,500}{11,250} = 10 \text{ yrs}$$

LONGHORN ARMY AMMUNITION PLANT

Shallow Solar Pond Performance Prediction

Shallow solar pond dimension parameters based on annual operation

Area: To be determined

Pond depth: 3 inches

$T_{ambient}$: 67°F

$T_{inlet\ to\ pond}$: 50°F

ΔT (from graph): 42.3°F temperature change in pond

T_{out} from pond: 92.3°F

Design load equals 620 MBtu/yr

$Q = mc\,\Delta t$

2.58 MBtu/day = (62.4 lb/ft^3 X flow rate ft^3/day) (1.0 Btu/lb °F) (42.3°F)

$$v_f = \frac{2.58 \times 10^6}{2.64 \times 10^3} = 977 \text{ ft}^3$$

$$\text{Area} = \frac{\text{volume}}{\text{depth}} = 977 \text{ ft}^3/.25 \text{ ft} = 3910 \text{ ft}^2$$

Storage volume = 977 X 7.48 gal. = 7310 gal.

Longhorn Payback Period Estimate

Estimated cost for five SSPs (16 ft X 50 ft each)

Total area = 4000 ft^2

Material and installation	$77,200
Design and engineering	16,800
	$94,000

Estimated annual fuel savings = 107 bbl oil = 4500 gal. oil

Estimate increase of oil so that average price per gallon at mid life of pond (10 yr life) = $2.50/gal.

4500 gal./yr X $2.50/gal. = $11,250

$$\text{Payback period} = \frac{\$94{,}000}{11{,}250} = 8.35 \text{ yrs}$$

LONE STAR ARMY AMMUNITION PLANT

Shallow Solar Pond Performance Prediction

Shallow solar pond dimensions based on annual performance

Area: To be determined

Pond depth: 3 inches

$T_{ambient}$: 64°F

$T_{inlet\ to\ pond}$: 50°F

ΔT (from graph): 41°F

$T_{out\ from\ pond}$: 91°F

Design load equals 620 MBtu/yr

$Q = mc\Delta t$ Daily load $= \frac{620\ \text{MBtu}}{240\ \text{days}} = 2.58$ MBtu/day

2.58 MBtu/day = (62.4) (flow rate) (1.0) (41.0)

$$\frac{2.58 \times 10^6\ \text{Btu/day}}{2.56 \times 10^3\ \text{Btu/day}} = 1.01 \times 10^3\ \text{ft}^3$$

$$\text{Area} = \frac{1010\ \text{ft}^2}{0.25} = 4040\ \text{ft}^2$$

Storage = 1010 ft^3 X 7.48 gal./ft^3 = 7600 gal.

Lone Star Payback Period Estimate

Estimated cost for five SSPs (16 ft X 50 ft each)

Total area = 4000 ft^2

Material and installation	$77,200
Design and engineering	16,800
	$94,000

Estimated annual fuel savings = 107 bbl oil = 4500 gal. oil

Estimate increase of oil so that average price per gallon at mid life of pond (10 yr life) = \$2.50/gal.

$$4500 \text{ gal./yr} \times \$2.50/\text{gal.} = \$11,250$$

$$\text{Payback period} = \frac{\$94,000}{11,250} = 8.35 \text{ years}$$

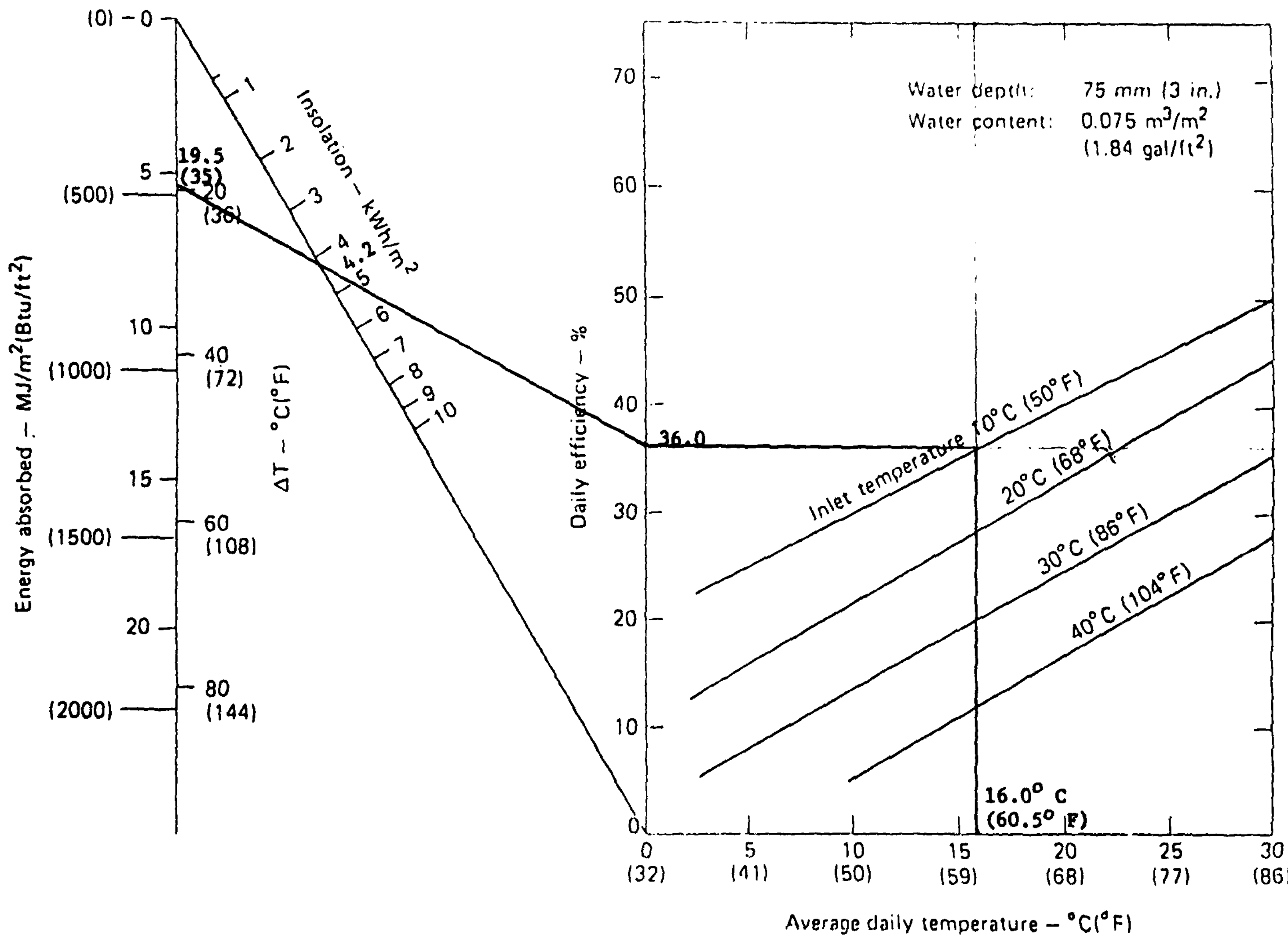

Figure B-1. Milan AAP--shallow solar pond performance prediction

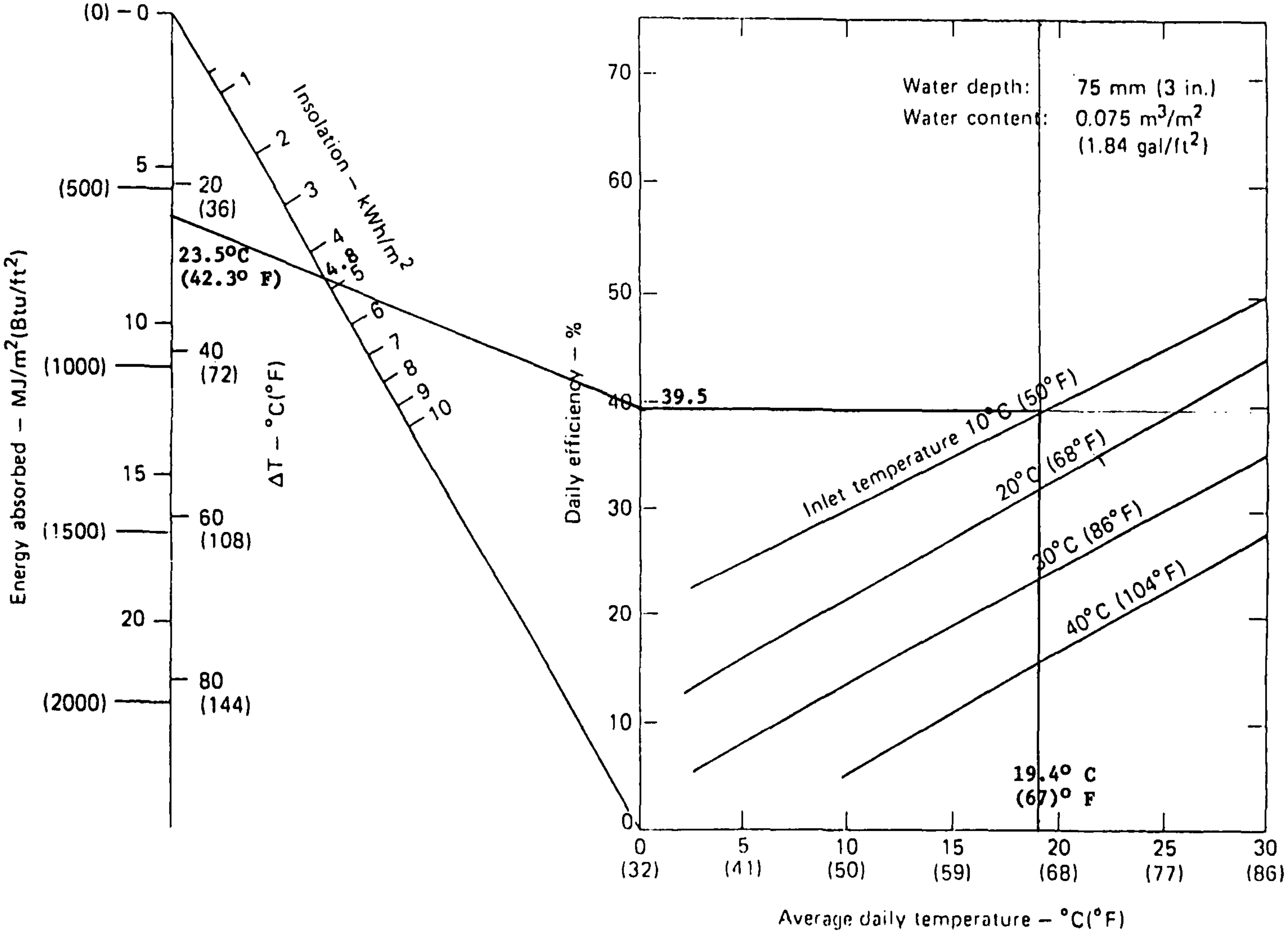

Figure B-2. Longhorn AAP--shallow solar pond performance prediction

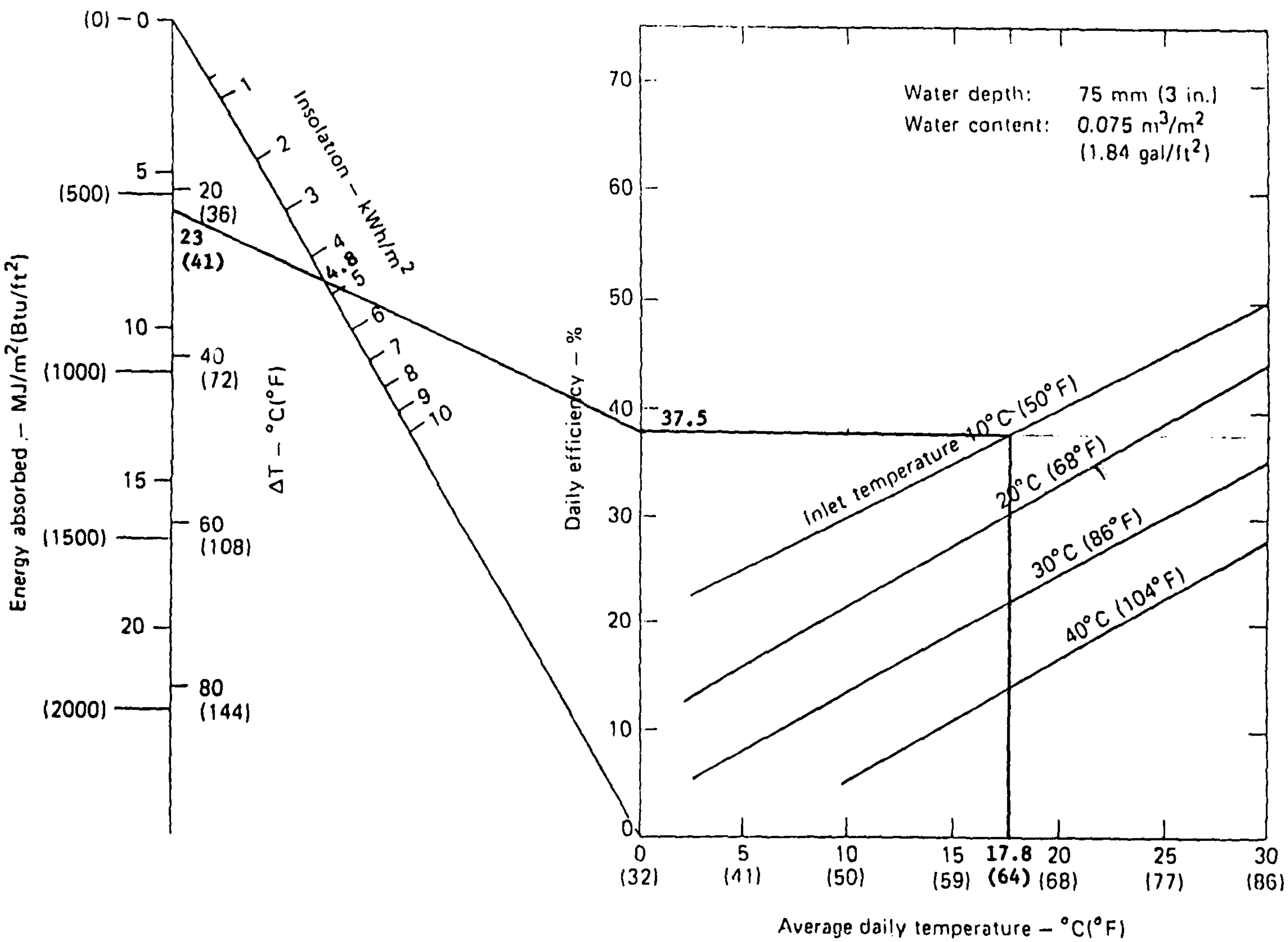

Figure B-3. Lone Star AAP--shallow solar pond performance prediction

Cost estimates for shallow solar pond module (12-ft width)

Item	Unit	Unit cost[a]	Total (required cost) per pond		
			50 ft	100 ft	200 ft
Bag					
PVC	ft^2	$ 0.45	588/$260	1175/$530	2350/$1100
Polybutylene	ft^2	0.05	588/$30	1175/$60	2350/$120
CSPE	ft^2	0.65	588/$380	1175/$760	2350/$1500
Glazing					
PVF coating (20-year life)	ft^2	0.38	600/$230	1200/$460	2400/$900
Acrylic coating (15-year life)	ft^2	0.30	600/$180	1200/$360	2400/$720
Insulation	ft^2	0.80	588/$470	1175/$940	2350/$1880
Concrete Curbing					
Ends	yd^3	190.00	1.2/$230	1.2/$230	1.2/$230
Sides	yd^3	190.00	2/$380	4/$760	8/$1520
Aluminum Side Curbing					
Ends	yd^3	190.00	1.2/$230	1.2/$230	1.2/$230
Sides	ft	5.00	100/$500	200/$1000	400/$2000
Glazing Bow					
Assembly	ea	12.00	15/$180	29/$350	57/$680
Glazing Edge Seal					
Clamp and clips	ft	0.56	100/$60	200/$110	400/$220
Concrete Anchors	ea	1.00	116/$116	228/$228	452/$452
Water Inlet/Outlet					
Pipe and valve	per pond	650.00	1/$650	1/$650	1/$650
Float Switches	ea	100.00	2/$200	2/$200	2/$200
Strapping	100 ft	$ 2.40	7.2/$20	14.4/$35	28.8/$70

[a] These are installed costs.

Auxiliary equipment.[a]

Item	Unit	Unit cost	Source
Pipe, cast iron (including trench)			
8-in.	ft	$14	Ref. 7
12-in.	ft	$22	Ref. 7
Pipe, asbestos cement			
8-in.	ft	$ 8	Ref. 7
12-in.	ft	$14	Ref. 7
Tanks			
Steel	gal	$0.40	Ref. 8
Steel, insulated	gal	$0.50	Internal estimate
Pump (with accessories)			
270 gal/min; 85 psi	ea	$10,000	Internal estimate
Excavation, grader	yd^3	$1.25	Ref. 8
Fill, gravel	yd^3	$9.00	Ref. 7
Fence, chain link			
(5 ft high)	ft	$5.55	Ref. 7

[a] This list is intended to show typical costs; it should not be construed as being a complete listing for every site. Because quantities of these items will vary from site to site, only unit costs are provided.

Cost estimate for shallow solar pond module (16-ft width).

Item	Unit	Unit cost[a]	Total (required/cost) per pond 50 ft	100 ft	200 ft
Bag					
PVC	ft^2	$ 0.45	775/$350	1550/$700	3100/$1000
Polybutylene	ft^2	0.05	775/$40	1550/$80	3100/$160
CSPE	ft^2	0.65	775/$500	1550/$1000	3100/$2000
Glazing					
PVF coating (20-year life)	ft^2	0.38	800/$300	1600/$600	3200/$1200
Acrylic coating (15-year life)	ft^2	0.30	800/$240	1600/$480	3200/$960
Insulation	ft^2	0.80	775/$620	1550/$1240	3100/$2480
Concrete Curbing					
Ends	yd^3	190.00	1.8/$350	1.8/$350	1.8/$350
Sides	yd^3	190.00	2/$380	4/$760	8/1500
Aluminum Side Curbing					
Ends	yd^3	190.00	1.8/$350	1.8/$350	1.8/$350
Sides	ft	5.00	100/$500	200/$1000	400/$2000
Glazing Bow					
Assembly	ea	12.00	15/$180	29/$350	57/$680
Glazing Edge Seal					
Clamp and clips	ft	0.56	100/$50	200/$100	400/$200
Concrete Anchors	ea	1.00	116/$100	228/$230	452/$450
Water Inlet/Outlet					
Pipe and valve	per pond	650.00	1/$650	1/$650	1/$650
Float Switches	ea	100.00	2/$200	2/$200	2/$200
Strapping	100 ft	$ 2.40	9.6/$25	19.2/$50	38.4/$100

[a]These are installed costs.

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